

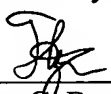
REMARKS

The above amendments have been made merely to place the application in better form for examination. No new matter has been added.

Each of the presently pending claims in this application is believed to be in immediate condition for allowance. Accordingly, the Examiner is respectfully requested to pass this application to issue.

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Respectfully submitted,

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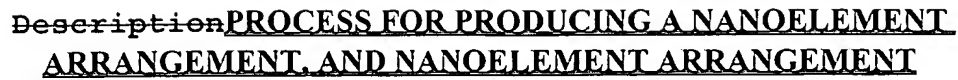
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CROSS-REFERENCE TO RELATED APPLICATION

FIELD OF THE INVENTION

BACKGROUND OF THE INVENTION

The use of carbon nanotubes is under discussion as a possible successor technology to silicon microelectronics. Basic principles of carbon nanotubes are described, for example, in ~~[1]~~-Harris, PJF (1999). "Carbon Nanotubes and Related Structures - New Materials for the Twenty-first Century". Cambridge University Press. Cambridge, pp. 1 to 15, 111 to 155. It is known that carbon nanotubes (depending on

the tube parameters) have an electrical conductivity ranging from semiconducting to metallic.

On account of their electrical properties, carbon nanotubes are being studied not only as a possible alternative to conventional active elements, such as field-effect transistors, diodes, etc., but also, on account of their high current-carrying capacity and small dimensions in the range of nanometres, as a replacement for conventional metallization material (aluminium, copper, etc.). Since the coupling of electrical switching elements in a circuit requires the production not only of simple point-to-point interconnects but also of branched electrical lines, there is a need for it to be possible to branch current paths using carbon nanotubes.

It is known from {2}Li, J. Papadopoulos, C Xu, J (1999) "Nanoelectronics: Growing Y-junction carbon nanotubes", Nature 402:253-254 to produce a Y-shaped junction of carbon nanotubes by forming a spot of catalyst material in an end section of a Y-shaped channel in an aluminium oxide template (Al_2O_3). Then, in accordance with {2}Li et al., a carbon nanotube with a Y-shaped junction is formed in the channel starting from the spot of catalyst material by means of pyrolysis of acetylene.

However, the process which is known from {2}Li et al. is restricted to the formation of branched carbon nanotubes inside a template.

At some locations, branched carbon nanotubes may randomly result during the synthesis of carbon nanotubes, for example using a CVD process (chemical vapour deposition). However, this process cannot be used to control the spatially defined formation of branched carbon nanotubes.

It is known from ~~{3}~~Cheung, CL, Kurtz, A, Park, H, Lieber, CM (2002)
"Diameter-Controlled Synthesis of Carbon Nanotubes". JPhysChemB 106:2429-2433
 to deposit iron clusters of predeterminable size on a substrate and to grow on carbon
 nanotubes using a CVD process starting from the iron clusters which have a catalytic
 action for the growth of carbon nanotubes. The diameter of the carbon nanotubes can
 be set by predetermining the diameter of the clusters.

~~{4}~~Murray, CB, Sun, S, Doyle, H, Betley, T "Monodispersive 3d Transition-
Metal (Co, Ni, Fe) Nanoparticles and Their Assembly into Nanoparticle Superlattices".
MRS Bulletin, December 2001, discloses a process by which metal clusters can be
 produced from 3d transition metals.

~~{5}~~Cao, A, Zhang, X, Xu, C, Liang, J, Wu, D, Wei, B (2000) "Carbon
nanotube dendrites: Availability and their growth model". Materials Research Bulletin
36:2519-2523, discloses a growth model for dendrites of carbon nanotubes.

~~{6}~~Sun, LF, Liu, ZQ, Ma, VC, Tang, DS, Zhou, WY, Zou, XP, Li, YB, Lin,
JY, Tan, KL, Xie, SS (2001) "Growth of nanofibers array under magnetic force by
chemical vapor deposition". Chemical Physics Letters 336:392-396, discloses the
 growth of carbon nanofibres under magnetic force by means of a CVD process.

~~{7}~~Zhu, H, Ci, L, Xu, C, Liang, J, Wu, D (2002) "Growth mechanism of Y-
junction carbon nanotubes". Diamond and Related Materials 11:1349-1352, discloses
 a growth mechanism of Y-junction carbon nanotubes.

~~{8}~~Gan, B, Ahn, J, Zhang, O, Rusli, Yoon, SE, Yu, J, Huang, OE, Chew, K,
Ligatchev, VA, Zhang, XB, Li, WZ (2001) "Y-junction carbon nanotubes grown by in

words, the first nanoelement, to which one or more clusters is/are attached, can be resuspended in a suitable solution/suspension, and can be applied to any desired substrate, for example using a pipette/micropipette or by spraying.

The first nanoelement with the at least one cluster attached to it can be subjected to a process step for forming the at least one second nanoelement, in such a manner that the at least one second nanoelement is grown on the at least one cluster. On account of their catalyst function, the clusters evidently form a nucleation location for the growth of a second nanoelement, with the result that a second nanoelement grows on the first nanoelement.

A CVD (chemical vapour deposition) process is preferably used to form the at least one second nanoelement on the catalyst material cluster of the first nanoelement. By way of example, for this purpose acetylene can be introduced into a CVD process chamber, with the result that the formation of the second nanoelement is set in motion. This nanoelement is preferentially grown on the first nanoelement on account of the catalytic action for the growth of nanoelements.

The catalyst material between the first and the at least one second nanoelement can then be nickel-plated, i.e., provided with nickel material at least at the surface. To improve an electrical contact resistance at the branching location between a first and a second nanoelement, it is possible, for example when iron material is used as catalyst material, to carry out a wet-chemical, electroless nickel-plating at the branching point, which is catalyzed by the existing iron material, in order to improve the electrical properties of the branching point.

and/or platinum. The said materials can advantageously be used as catalyst material, in particular if the nanoelement used is a carbon nanotube.

The following text describes the nanoelement arrangement according to the invention in more detail. Refinements of the process for producing the nanoelement arrangement also apply to the nanoelement arrangement, and vice-versa.

With the nanoelement arrangement according to the invention, it is possible for only part of the first nanoelement to be covered with catalyst material for catalyzing the growth of nanoelements. As a result of another partial region of the first nanoelement being free of catalyst material of this nature, it is possible to predetermine in a targeted manner those locations on which a second nanoelement can be grown.

The first nanoelement can be grown in a pore introduced in a substrate. In this way it is possible, for example, for the first nanoelement to be formed as a vertical nanoelement which extends along a preferably vertical pore introduced in a substrate. If the first nanoelement projects out of the pore and a spot of catalyst material is formed at the projecting region of the nanoelement, it is possible for a second nanoelement to be grown on the first nanoelement.

The first nanoelement may be grown in the pore on a metallization plane in the substrate. In this way, it is possible for the first nanoelement to already be electrically coupled to a metallization plane, and in this case the metallization plane can in turn be coupled to an integrated circuit in the substrate or may form part of this circuit. Since the first nanoelement and/or the second nanoelement is preferably electrically conductive or semiconducting, it is possible to create a continuous, electrically conductive connection between the integrated circuit and the first or second

nanoelement. This is advantageous with a view to forming an integrated circuit with a dimension in the nanometre range.

The first and/or the at least one second nanoelement and/or at least one additional nanoelement may be grown on top of one another and/or next to one another. In this way, it is possible to produce an areal or three-dimensional arrangement of nanoelements, so that it is clearly possible to form a network of interconnects which is suitable for numerous applications (for example memory cell circuits or logic circuits).

The first and/or the at least one second nanoelement may include a nanotube, a bundle of nanotubes or a nanorod. The nanorod may, for example, include silicon, germanium, indium phosphide, gallium nitride, gallium arsenide, zirconium oxide and/or a metal. The nanotube may, for example, be a carbon nanotube, a carbon-boron nanotube, a carbon-nitrogen nanotube, a tungsten sulphide nanotube or a chalcogenide nanotube.

The first and/or the at least one second nanoelement may, for example, be a carbon nanotube. In this case, iron, cobalt and/or nickel are preferred for use as catalyst material. It is also possible to use an alloy of iron and/or cobalt and/or nickel with aluminium, titanium, molybdenum and/or platinum.

The nanoelement arrangement of the invention may include an integrated circuit which is coupled to the first and/or the at least one second nanoelement. Therefore, the nanoelements may be connected to an integrated circuit, for example in order to couple the integrated circuit to miniaturized components.

reduced or atmospheric pressure at 300°C to 1000°C. A CVD process is suitable for forming the second nanoelements.

The metal clusters which form the catalyst material may, for example, be produced using the processes described in [3], [4] Cheung et al., Murray et al.

By way of example, it is possible to use multi-walled carbon nanotubes as first nanoelements. These can be produced using a CVD process. The carbon nanotubes produced can be used directly or may be oxidized in order to improve the solubility with a suitable chemical (for example sodium hypochlorite NaOCl). The carbon nanotubes can be treated with a suspension of iron clusters in toluene at room temperature. The iron clusters can be produced from iron pentacarbonyl ($\text{Fe}(\text{CO})_5$) and oleic acid ((Z)- or cis-9-octadecenoic acid, $\text{C}_{18}\text{H}_{34}\text{O}_2$). The carbon nanotube material which is in suspension can be filtered off and solvent residues can be removed. It can be resuspended using dimethylformamide ($\text{C}_3\text{H}_7\text{NO}$). A drop of this solution can be applied to a substrate, or a solution which has been diluted with isopropanol can be sprayed on. During this process step, part of the substrate can be covered in order for a subsequent lift-off patterning process to be carried out, for example by means of photoresist. In this way, it is possible to ensure that carbon nanotubes are applied only to desired surface regions of a substrate. After the solution has been applied and after a possible subsequent lift-off process for removal of the photoresist, the substrate can be introduced into a reaction furnace after it has been dried. Subsequently, second carbon nanotubes can be synthesized branching off from the first carbon nanotube. Then, in order to improve the electrical contact resistance at

a respective branching point, a preferably wet-chemical, electroless nickel plating step can be carried out at the branching point.

It should be noted that according to the invention the catalyst material used may be not only metal clusters from 3d elements, such as iron, cobalt or nickel, which have been produced from the corresponding carbonyls, but also, for example, those clusters which can be produced from salts of organic acids with the aid of diols as reducing agent. Alloys of the abovementioned metals with Al, Ti, Mo, Pd, Pt, Ru, Ph, Os or Ir are also possible.

BRIEF DESCRIPTION OF THE DRAWINGS

Exemplary embodiments of the invention are illustrated in the figures and are explained in more detail in the text which follows. In the drawing:

Figures 1A and 1B show diagrammatic views of suspensions during a process for producing first carbon nanotubes covered with catalyst material clusters using a process for producing a nanoelement arrangement according to a preferred exemplary embodiment of the invention,

Figures 2A and 2B show cross-sectional views of layer sequences during the process for producing a nanoelement arrangement according to the preferred exemplary embodiment of the invention,

Figure 2C shows a cross-sectional view through a nanoelement arrangement in accordance with the preferred exemplary embodiment of the invention,

Figures 3A to 3C show electron microscope images of nanoelement arrangements in accordance with preferred exemplary embodiments of the invention.

Identical or similar components in different figures are provided with identical reference numerals.

The illustrations in the figures are diagrammatic and not to scale.

DETAILED DESCRIPTION OF THE PREFERRED MODE OF THE INVENTION

The text which follows describes, with reference to Fig. 1A, Fig. 1B, Fig. 2A to Fig. 2C, a process for producing a carbon nanotube arrangement in accordance with a preferred exemplary embodiment of the invention.

Fig. 1A shows a container 100 which contains a suspension of toluene solvent 101 and iron clusters 102. The iron clusters are surrounded by a thin film of oleic acid (not shown).

Fig. 1B shows the operating state of the container 100 after carbon nanotubes 110 have been introduced into the suspension using a CVD process. The carbon nanotubes 110 are surrounded along most of their length with a protective layer (not shown) of a photoresist, and the carbon nanotubes 110 are only free of the protective layer in a region surrounding an end section of the carbon nanotubes 110. After the carbon nanotubes 110 partially covered with the protective layer have been introduced into the suspension of toluene 101 and iron clusters 102, iron clusters 102 attach themselves only to those locations of the carbon nanotubes 110 at which the latter are free of the protective layer. The oleic acid sheath by which the iron clusters 102 are

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nanotubes 323 are shown starting from catalyst material spots 312 on the primary carbon nanotube 321.

Fig. 3C shows yet another electron microscope image 320, in which a secondary carbon nanotube 323 has been grown starting from a catalyst material spot 322 on a primary carbon nanotube 321.

~~[8] Gan, B, Ahn, J, Zhang, Q, Rusli, Yoon, SF, Yu, J,
Huang, QF, Chew, K, Ligatchev, VA, Zhang, XB, Li, WZ
(2001) "Y junction carbon nanotubes grown by in situ
evaporated copper catalyst", Chemical Physics
Letters 333:23-28~~